National Bureau of Standards

September 1955
Volume 39
Number 9

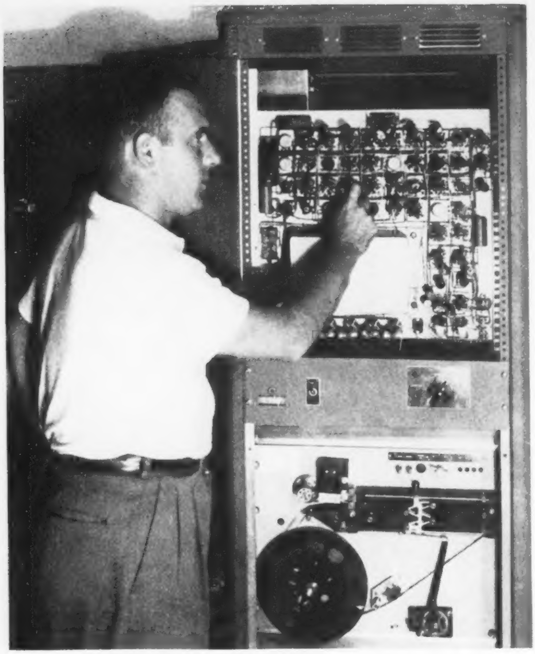
Technical News Bulletin

High-Density Tape Recording for Digital Computers

THE NATIONAL BUREAU OF STANDARDS recently developed a method for closely packing digital pulses on magnetic tape. This method promises future useful application in the field of electronic computers. Such high-density storage can greatly reduce problem solution time by providing more rapid access to information recorded on external magnetic tape units. In a series of experiments performed by J. R. Sorrells of the data processing laboratory, both continuous-current and pulse techniques were investigated to achieve densities in the range of 500 to 700 pulses/in. Recording and reading circuitry was also developed to provide large-amplitude playback signals with error-free differentiation between binary *ones* and *zeroes*.

An integral part of many large high-speed electronic computers is some type of magnetic tape or wire storage system which serves as an input-output means, as an external low-speed memory, or in some cases as both. Many types of mathematical problems require extensive external storage. In solving these problems relatively little actual computation is performed, but a great deal of data must be handled and assimilated by the computer. Ideally, a magnetic tape system should supply or receive data from the machine fast enough so that the computer could proceed with the problem solution at its normal rate. In reality, however, the maximum rate the tape can accommodate information is usually very slow compared to the machine's internal speed because tape velocity is limited and information is commonly stored on the tape at comparatively low density. As a consequence, the majority of problem solution time is not spent in computation, but in the performance of input-output or tape storage operations. The Bureau's investigation has been directed toward improving magnetic tape storage techniques. Such developments would permit more rapid transmission of information to the computer by increasing the number of digital pulses recorded on each inch of the tape, thereby increasing the over-all efficiency of the machine. Already in operation with the NBS electronic computer, SEAC, are tape drive units [1] that provide high-speed starting, stopping, and reversing of magnetic tapes, together with maximum practical tape speeds.

One variation of the non-return-to-zero (NRZ) system of tape recording was selected for the present investigation. In this system, as ordinarily applied, current sufficient to saturate the tape is maintained in the recording head at all times, but the polarity is changed each time a binary one is to be recorded. When a binary *zero* is to be recorded, the current is not



Equipment developed for closely packing digital pulses on magnetic tape. This computer accessory may reduce problem solution time by providing more rapid access to tape recorded information. Reading and recording circuitry (top) produce large-amplitude playback signals when 500 to 700 pulses per inch are recorded on tape. Tape transport mechanism (bottom) is a modification of a commercially-available model.

changed. This type of recording produces a single change in magnetic flux on the tape for each binary *one* and no change in flux for a *zero*, so that on playback a voltage is produced only when a *one* is read. This method has two disadvantages: (1) a continuous current must be maintained in the head during recording and (2) the polarity of the current must be switched rapidly. Unless center-tapped head windings are used, these requirements often lead to rather complicated driver circuits that consume considerable power. To overcome these drawbacks, the Bureau used a digital pulse technique instead of the continuous current method to achieve NRZ tape magnetization.

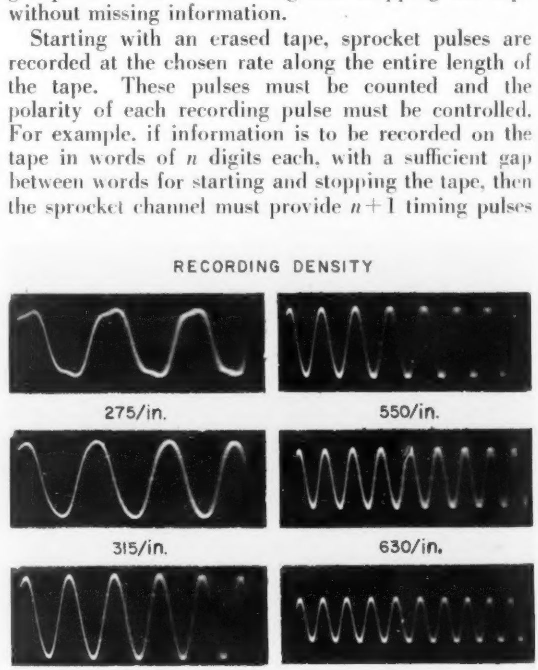
In application, the pulse technique is analogous to the continuous current method. To record a binary *one* with the pulse technique, a pulse of opposite polarity to the previous pulse is recorded. To record a binary *zero*, a pulse of the same polarity as the previous pulse is recorded. Thus, on playback, there is a single voltage swing for each recorded *one*, and no voltage for a *zero*.

To find the maximum usable pulse density, a number of recordings were made on tapes that had previously been erased with alternating current. For each recording, the tape speed was held constant, the pulse duration was 2 μsec, and the pulse current was 60 ma. The only parameter that was changed was the pulse repetition rate; this was increased so that for successive recordings the pulses were crowded closer and closer together. When the recordings were read back, it was found that the playback voltage increased with pulse density until a maximum of 440 pulses/in. was reached. The voltage then began to decrease for greater densities, but so slowly that even at 730 pulses/in. the output signal amplitude was still usable.

In the NBS recording system, the recording rate and the exact location of each recorded digit is determined by timing pulses derived from a "sprocket" channel, prepared in advance of the recording operation. The word length can be chosen arbitrarily, depending on the equipment with which the storage system is to be used. If the number of digits per word is n, then the sprocket channel must provide $n+1$ timing pulses per word. The extra pulse is used to set up a reference condition at the beginning of each word. In preparing the sprocket channel it is also necessary to consider the speed and acceleration time of the tape drive so that a sufficient gap can be left between words or groups of words for starting and stopping the tape without missing information.

Starting with an erased tape, sprocket pulses are recorded at the chosen rate along the entire length of the tape. These pulses must be counted and the polarity of each recording pulse must be controlled. For example, if information is to be recorded on the tape in words of n digits each, with a sufficient gap between words for starting and stopping the tape, then the sprocket channel must provide $n+1$ timing pulses

RECORDING DENSITY



Oscilloscope playback signals from pulses recorded on previously erased tape. For each recording tape, speed is held constant, pulse duration is 2μ sec, and pulse current is 60 ma. Pulse repetition rate is increased for each successive recording. Photos show that playback voltage increases with pulse density until maximum of 440 pulses per inch is reached. Voltage then begins to decrease, but at 735 pulses per inch the playback signal is still large enough to be usable.

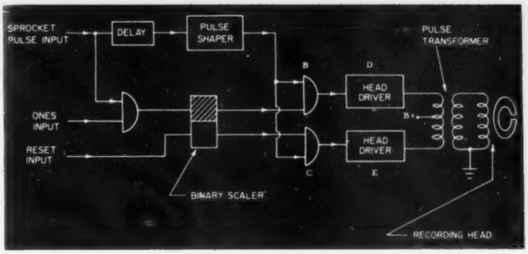


Diagram of the high-density tape recording system. Sprocket pulses provide exact timing and spacing of information pulses. "Ones input" is for information pulses, and "reset input" is pulse that occurs at beginning of each information word. In operation, a pulse is recorded every time there is a sprocket pulse: If a binary one (information) is to be recorded, the recorded pulse is of opposite polarity to the previus pulse. For a binary *zero*, a pulse of same polarity as previous pulse is recorded.

per word, and so for $n+1$ times the polarity of the pulses in the sprocket channel must alternate. After these $n+1$ pulses have been recorded, a number of pulses of the same polarity are recorded to provide a gap of sufficient length. Since pulses of the same polarity recorded at a high enough density produce no change in tape polarization, there will be no playback signal from the gap. After the required number of like polarity pulses have been recorded, the polarity of the recording pulses then again alternates $n+1$ times. The whole length of the sprocket channel is recorded in this manner, and the tape is then ready for use. During an information recording operation, the sprocket pulses are read from the tape and fed back to a coincidence gate, where they are combined with the pulses for the information channel. In this way, the information pulses are accurately timed and located on the tape. The same procedure is applicable to parallel operation where reading and recording is done in a number of information channels simultaneously under the control of a common sprocket channel. Each information channel would, of course, require its own separate reading amplifier and recording circuit.

In a tape storage system such as this, where a sprocket channel is used both to interpret the playback signals from the information channels and to time the pulses recorded in the information channels, a problem arises from the close proximity of the read-record heads. During a recording operation, each timing pulse derived from the sprocket channel initiates a recording pulse in one or more of the information channels, and if the heads are closely spaced, this pulse of current through an information head induces a signal into the sprocket channel head that may be from 20 to 50 times the amplitude of the average tape signal. In a conventional amplifier, this large crosstalk signal would undoubtedly cause grid blocking as well as spurious signals, so the sprocket channel amplifier had to be of special design.

Shielding between the heads reduced the crosstalk signal somewhat, but the residual noise-to-signal ratio of 20 to 1 was still intolerable. Since the sprocket head was located between the two recording heads, it was possible to reduce significantly the crosstalk signal. This was accomplished by orienting the windings of the recording heads so that they were in opposition to each other, thereby causing their magnetic fields to cancel. However, some crosstalk was still present because of slight geometric differences between the heads, minor differences in the signal levels, and a small capacitive coupling to the sprocket head. In order to suppress further the effects of the crosstalk signal, advantage was taken of the fact that the two signals with which the sprocket channel amplifier is concerned are made up of widely different frequency components. The desired signal from the tape consists of packets of nearly pure sine waves, whereas the undesired crosstalk signal is made up primarily of much higher-frequency components since it is induced by a recording pulse which is only 2 μsec in duration. This knowledge was used to design and build a low-pass amplifier for the sprocket channel. At the output of this amplifier, the crosstalk signal is reduced to only one-fifth the amplitude of the tape signal. Thus attenuated, the crosstalk presents no further problem since it is now within the range of conventional amplitude discrimination means.

The information channel circuitry is nearly identical with the sprocket channel circuitry; the main difference is in the reading amplifiers. While the sprocket channel amplifier was purposely designed to suppress the

RECORDED PATTERN
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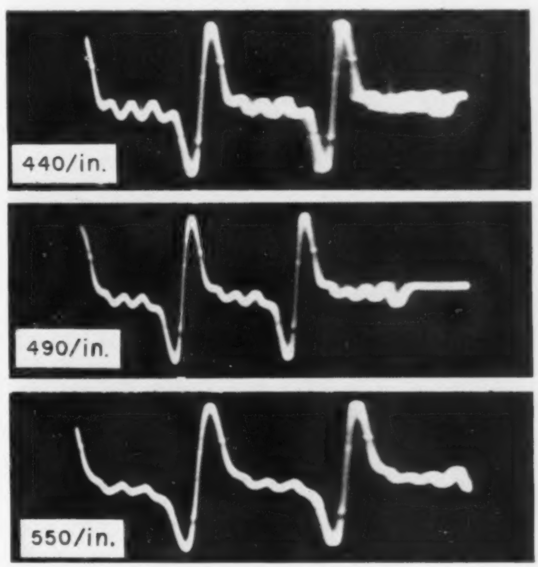


Typical playback signals from an information channel using high-density recording methods. Each lobe of the signal represents a binary *one* and is easily differentiated from the binary *zeroes* by the reading circuitry.

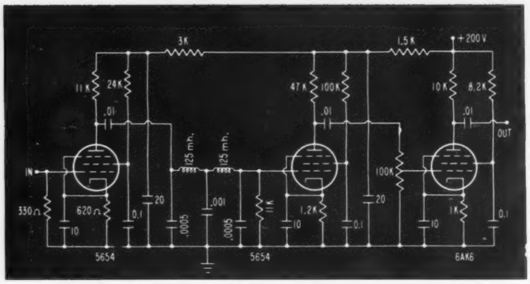


Diagram of sprocket channel amplifier with low-pass amplifier included. Information channel amplifier is similar except that the low-pass filter is omitted to give amplifier a good overall high-frequency response.

high-frequency response, the information channel amplifier has no such requirement. A satisfactory design was achieved simply by reproducing the sprocket channel amplifier with the low-pass filter omitted.

Although this tape storage system has not yet been completely and rigorously tested with a computer under actual operating conditions, it has been given extensive laboratory trials to determine the reliability of the reading and recording circuitry at different recording densities. For these tests the sprocket channel was recorded and used as it would be in actual operating conditions to control the recording and reading of the information channels. By recording words of information that contain a known number of *ones* and *zeroes*, it was possible to obtain a fair check of the performance of the system by counting the number of *ones* or *zeroes* on playback. Without taking any precautions to prevent errors from tape flaws, several runs of one to three million digits were recorded and read at densities of 500 to 600 digits per inch without apparent errors. It is expected that similarly successful results will be obtained when the system is tried with the NBS computer, SEAC, under actual operating conditions.

[1] Magnetic tape "memory" for SEAC, *Tech. News Bul.* **35**, *161* (*Nov. 1951*).

Continuous Recording of Sound Transmission Loss

THE ACOUSTICAL PROPERTIES of construction materials play an important part in designing homes, offices, and factories. For least expensive effective soundproofing design, architects and engineers require comprehensive data. One of the most critical acoustical properties is sound transmission loss (STL)—a factor directly related to the sound attenuating qualities of a material.

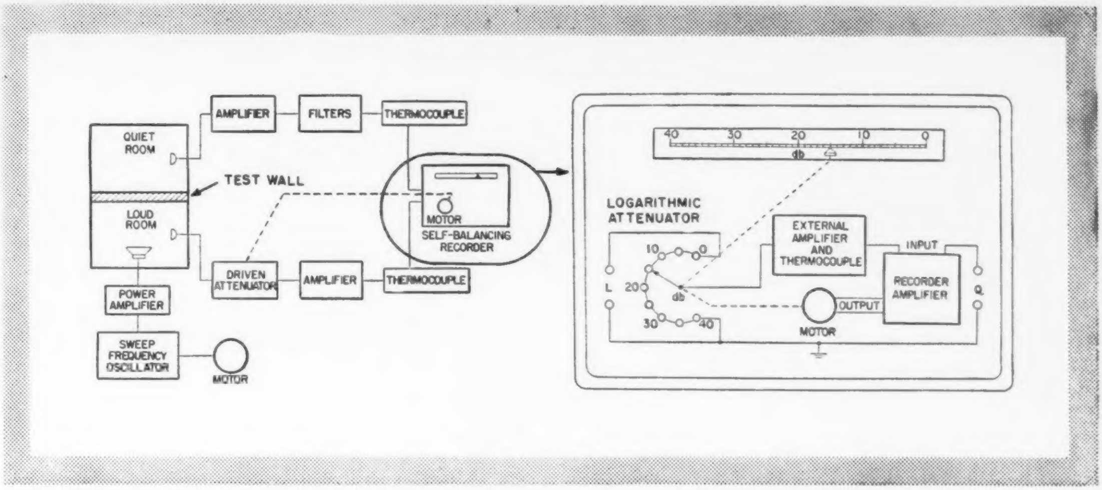
Recently the Bureau developed a rapid, accurate method for determining a wall's STL over a wide range of frequencies. The method utilizes an adapted commercial recorder which presents a continuous record of the decibel difference between sound levels in two rooms separated by a test wall. The recorder adaptation was made by R. V. Waterhouse and R. K. Cook of the sound laboratory.

In measuring the STL of walls, floors, and other structures, it is often desirable to obtain an accurate curve of STL versus frequency over the range of 100 to 4,000 cps. Usually STL figures are measured with a number of discrete noise bands, each centered at a particular frequency. An approximation of the test panel's STL curve can be obtained by plotting these data and connecting the points with straight lines. Such an approximation is satisfactory for most purposes, but in studying certain aspects of the transmission of sound through panels—for example, edge or coincidence effects—a more accurate procedure is needed.

A partial solution to this problem is obtained as follows: The panel to be tested is used as a wall common to two adjacent rooms. The room containing sound-producing equipment is called the *loud room;* the other is called the *quiet room.* Sound apparatus records the average sound pressure level in each test room as a continuous function of frequency, and the STL of the test panel is determined by subtracting the quiet room curve from the loud room curve. However, it is much more convenient to be able to record directly in decibels the difference between the sound levels in the two test rooms. This can be done by the Bureau's method, which presents the STL of the test panel as a chart reading.

In this method the sound laboratory uses a self-balancing commercial recorder wired ordinarily as a voltmeter. In this arrangement, voltage to be measured is balanced against a known voltage from a standard cell contained within the instrument. The unknown voltage is fed across a resistance potentiometer, and part of it is tapped off and compared with the standard voltage. The difference voltage is applied to an amplifier whose output actuates a motor. The motor drives the sliding contact of the potentiometer in the direction that minimizes the difference voltage until at the balance point the two voltages are equal. The position of the sliding contact gives the value of the unknown voltage which is recorded by the apparatus.

Two modifications were made to make the instrument record the difference in decibels between two signals. First, the standard cell was removed, and one of the incoming signals used in its place. Second, a logarithmic attenuator was installed in place of the linear slide wire. The attenuator has 40 steps of 1 db each, set around in a circle. Thus the recorded plot covers the range 0 to 40 db linearly. The scale can be easily changed from this range to other ranges by in-



Block diagram (left) of setup used for automatically recording sound transmission loss (STL) of walls and floors. Test wall separates the loud room and quiet room. The loud-room signal is continuously attentuated to match the signal of the quiet room. The two signals are balanced at an attenuator setting which is determined by the STL of the panel. Drawing (right) shows self-balancing recorder modified to read decibel difference between two signals. Microphone voltages from loud and quiet rooms are fed into the recorder at L and Q, respectively. Difference in the sound levels of the two rooms is indicated in decibels on the scale.

serting a fixed attenuator, or by adjusting the gain of the amplifiers.

In operation, the loud and quiet rooms are separated by the panel whose sound transmission loss is to be measured. An oscillator in the loud room supplies a warbled signal whose center frequency is motor driven over the required frequency range. Sounds from the two rooms are picked up by microphones and fed into separate channels which amplify, filter, and rectify the associated microphone voltages. The logarithmic attenuator continuously reduces the voltage from the loud room to the value of the voltage from the quiet room. The two voltages are automatically balanced at an attenuator setting which is determined by the STL of the panel.

To record accurate differences in decibels, the gain of the amplifiers of both channels (quiet and loud) must not vary differentially during the measurement. In the setup used at NBS a stabilized power supply makes errors from this source negligible.

Data taken with this equipment differ slightly from the true STL curves. The difference lies in the quiet-room absorption correction and the variation in response of the microphones in the two rooms. By suitable choice of microphones, the two corrections can be made to cancel out partially, so that the final correction need not be more than 2 db. This is small enough to ignore in assessing the main features of the STL curve and, if necessary, could be corrected by an electrical network inserted in one channel.

Two New Publications in Mathematics

THE National Bureau of Standards has recently issued two new publications in its Applied Mathematics Series. The two volumes are entitled *Experiments in the Computation of Conformal Maps*, edited by John Todd; and *Tables of Sines and Cosines for Radian Arguments:* AMS42 and AMS43, respectively.[1]

The first volume contains six papers describing and evaluating three computational experiments in conformal mapping. This subject is principally important in electromagnetic theory, aircraft wing design, and hydrodynamics. The two lead papers treat conformal mapping of a unit circle into an ellipse. The following two papers are "On the solution of the Lichtenstein-Gershgorin integral equation in conformal mapping." The fifth paper deals with "Two numerical methods in conformal mapping." The last paper discusses a computation performed using one of the suggested methods.

The tables of sines and cosines are an extended and corrected version of a volume known as Mathematical Table MT4, published by the Works Progress Administration in 1940. Essentially the old volume is unchanged. The main table has been extended to $x=25.2$, the approximate equivalent of four complete circles. The table $p(1-p)$ was replaced by the more useful table $\frac{1}{2}p(1-p)$. A more useful table of conversion factors from radians to degrees (and vice versa) is provided.

[1] *AMS42, 61 pages, 40 cents; AMS43, 278 pages, $3.00. Order from U. S. Government Printing Office, Washington 25, D. C.*

New Radiochemistry Laboratory

Interior view of "hot lab" in the NBS radiochemistry laboratory where solutions of radioactive materials are prepared for use as standard samples. *Right:* Ampoules containing standard samples.

A NEW radiochemistry laboratory for use in preparing and distributing standard samples of radioactive materials has been established at the National Bureau of Standards. The laboratory will be operated by the Bureau's Radioactivity Section under the supervision of W. B. Mann. Facilities include equipment for remote control operations under chemical hoods, specially built lead and concrete protective shieldings, and a system for proper disposition of radioactivity from the exhausts of the chemical hoods. The resources of this laboratory are expected to expedite greatly the Bureau's program of radioactive sample distribution.

As custodian of the Nation's standards of radioactivity, the Bureau carries on a broad research and development program aimed at producing the radioactive standards required for medical, scientific, and commercial uses. The new radiochemistry laboratory is one of six related facilities which have been established at the Bureau to provide this service. The other laboratories perform alpha-ray measurements, radioisotope standardization, nuclear spectroscopy, radon testing, and gamma-ray measurements.

The radiochemistry laboratory is primarily responsible for the preparation, maintenance, and distribution of approximately 57 different radioactive nuclides and ores.[1] Included in this group are carbon-14, sodium-22, phosphorus-32, cobalt-60, iodine-131, and gold-198. New uses for these and other nuclides in industry, physics, and medical research and therapy have increased tremendously the demand for radioactive standard samples. For example, in 1949 the National Bureau of Stanards received requests for 527 such samples; in 1954 the demand had increased to 1,098 samples. With the need well established for a radiochemistry laboratory equipped to prepare nuclide samples on a rather large scale, construction of the facilities was begun in 1954.

Five rooms combine to make up the NBS radiochemistry laboratory: An office; two specially equipped "hot" rooms for handling bulk material and for basic and applied chemical research; a counting room where 2π formamide[2] calibrations can be performed; and a "C^{14} and H^3 room" where internal gas and liquid scintillation counting facilities are provided for low energy beta emitters. The "hot" rooms are also used for the preparation of radioactive sources for nuclear spectroscopic research.

The new laboratory is located on the top floor of the materials testing laboratory building. This site was selected because it permits simple arrangements for proper disposal of radioactivity from the exhausts of the chemical hoods. The flow of air through the hoods of each laboratory is of the order of 4,000 cubic feet per minute, the air entering the laboratory through filters to prevent excessive deposition of dust particles. The laboratories are fully equipped for chemistry operations. In addition, they contain special sinks with foot-operated faucets, a stainless steel decontamination sink, and semiautomatic pipetting equipment.

Radioactive standard preparation involves a care-

fully controlled procedure, beginning with receipt of bulk material from Oak Ridge National Laboratory and ending with issuance of a standard sample of certified strength. The material is usually received as a salt in a concentrated acid solution. Gold-198, however, is acquired as a small piece of irradiated gold foil. A single master solution is produced by introducing the received substance into a solution of a stable (nonradioactive) isotope of the same element. The stable isotope acts as a carrier for the radioactive one. The master solution has a nominal radioactivity of 500 microcuries per milliliter. Subsequent to this, accurate volume dilutions are made using carrier solutions to obtain the desired ampoule solution. The ampoule solution is then standardized in the beta- and gamma-ray standards laboratory by absolute counting techniques.[3]

Solution standards, specified in terms of disintegrations per second per milliliter, are subsequently prepared using semiautomatic pipetting equipment. Approximately 3 ml of the solution are delivered to a glass ampoule. The ampoule is immediately flame-sealed, and the standard sample of radioactivity is then ready for distribution. To permit shipment of these standards without AEC clearance, the ampoules are limited to a nominal activity of 3 microcuries per milliliter for nuclides with half-lives of less than 30 days. This activity is reduced by a factor of ten for half-lives of more than 30 days.

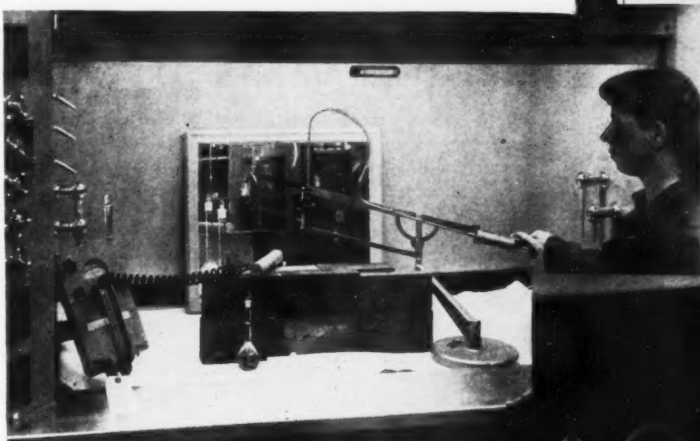
The radiochemistry laboratory program is expected to increase steadily as a result of the expanding uses of radioisotopes in medicines and as biological and industrial tracers. Further work is expected on the program to intercompare radioactive standards and methods of measurement with Canada and Great Britain and other interested countries. On the basis of the intercomparisons, it is planned that international standards of a number of nuclides be established, beginning with phosphorus-32 and cobalt-60.

[1] Standard samples and reference standards issued by the National Bureau of Standards, *NBS Circular 552. For sale by the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C. Price 25 cents.*

[2] Determination of carbon-14 in solutions of C^{14}-labeled materials by means of a proportional counter, *by A. Schwebel, H. S. Isbell, and J. D. Moyer, J. Research NBS* **53**, *221* (*1954*).

[3] Standardization of beta-emitting nuclides, *by H. H. Seliger and A. Schwebel, Nucleonics* **12**, *No. 7, 54* (*1954*).

Plastic dry box used to prepare standard samples of alpha- and beta-ray emitters. Radioactive materials are handled with rubber gloves attached to the walls of the box. A small exhaust fan (upper right) removes any airborne radioactivity from the box. The laboratory worker is using a survey meter to determine level of radioactivity. →



A semiautomatic pipet being used to withdraw an exact amount of radioactive solution from a master solution behind protective lead-brick barrier. A survey meter (left) indicates radiation intensity. ←

Equipment for preparing low-level radioactive solutions and sources. Deposits of radium D in a lead acetate solution are being made on palladium-covered silver disks. The ultra-microburet (right) is used to deliver a very small, but accurately known, volume of the solution onto the disk. →

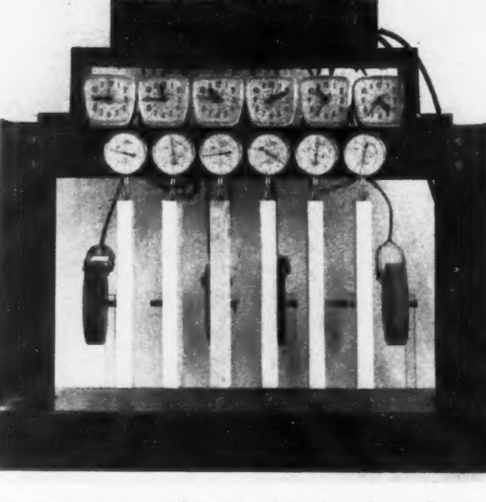
Cracking Resistance of Hydraulic Cements

THE cracking resistance and shrinkage rates of a number of hydraulic cements have been under study at the Bureau as part of a general investigation of the properties of cements and concretes. Results so far indicate that cements with high shrinkage rates after hardening tend to crack and craze sooner than cements with lower shrinkage rates. Included in the study were 180 samples of portland cements from all areas of the United States, 7 portland blast-furnace slag cements, 2 portland-pozzolan cements, and 5 portland cements from other countries. The investigation was conducted by D. N. Evans, A. C. Figlia, and R. L. Blaine of the concreting materials laboratory.

Resistance to cracking is an important factor in durability of concrete. If the aggregates of various concretes are the same, the cement having the greatest resistance to cracking will produce the most durable concrete. Cracks may be long and deep, extending for some distance along the surface and into the concrete: or they can occur as short random breaks on the surface, sometimes called map cracking or crazing. Large cracks tend to cause structural failure, while crazing serves as a source of spalling or disintegration of the surface.

Two types of specimens—prismatic and annular—were prepared from water-cement mixtures of each sample.[1] The prism, 1 in. square by 10 in. long, was used to determine the unrestrained drying shrinkage of the hardened cement paste. The annular specimen, also 1 in. square in cross section, was used to determine the time required for the cement to crack under restrained shrinkage. The annular specimen was formed around a steel disk 1 in. thick and 4¼ in. in diameter. This core was coated with grease to prevent the cement from adhering to it. Since the disk was left inside the annular specimen, any stress introduced on drying and shrinkage could be relieved only by the deformation or cracking of the hardened cement paste. Both types of specimens had approximately the same exposed area.

Each cement sample was mixed with water, and a prismatic and an annular specimen were formed from



Apparatus constructed to test prismatic and annular specimens of six cements. Dial gages measure length changes of prisms due to shrinkage. Electronically controlled clocks indicate time at which annular specimens break. The equipment is photographed once an hour by an automatic camera. The pictorial records indicate length attained by each prism when corresponding annular specimen breaks.

the mixture. The specimens were covered to prevent moisture loss and cured at 73° F and 95 percent humidity for 24 hr. Upon removal from the molds, the specimens were exposed to air in the laboratory at 73° F and 50 percent humidity. Under these conditions some drying took place. The length of the prism was measured when removed from the mold, and length changes were recorded periodically up to an age of 28 days.

The specimens were supported in a simple metal rack and arranged so that the length of the prisms could be measured continuously with dial gages. A line of conducting paint around each annular specimen was connected to an electronic detecting device that turned off an electric clock when the specimen broke

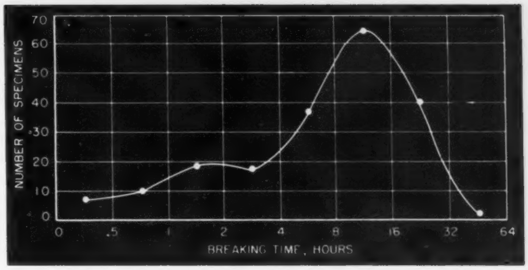
TABLE 1. *Properties of eight hydraulic cements*

Shrinking rates and breaking times of 4 cements breaking at early ages, and of 4 cements breaking at later ages, and some of the properties usually associated with high shrinkage.

Cement number	Type	Breaking time (annular specimen)	Shrinkage at time of break*	Shrinkage at 1 hr*	Shrinkage at 28 days*	Fineness air permeability	Compressive strength of 1:2.75 mortar cubes 1 day	Sulphite	Tricalcium aluminate	Tricalcium sulphate	Total alkali	Water/cement ratio (by weight)
		hr:min	%	%	%	*cm²/g*	*psi*	%	%	%	%	%
104	III	0:11	0.009	0.020	0.223	5850	2470	2.4	8	65	0.13	23.2
54	I	0:30	.013	.017	.255	3110	1720	2.2	12	54	.70	25.6
105	III	1:14	.018	.016	.275	4580	1540	1.8	6	55	.60	23.2
65	I-A	2:15	.017	.013	.270	2990	625	2.0	11	40	1.03	23.3
67	II	28:11	.058	.010	.207	2980	370	1.5	7	43	0.47	23.4
81	V	26:25	.043	.013	.172	3560	860	1.7	6	44	.53	22.8
118	V	33:12	.044	.012	.158	2910	720	1.4	4	42	.42	22.0
23	I	45:17	.126	.911	.221	3220	890	1.5	9	54	.39	23.2

*Shrinkage of prismatic specimens at indicated time.

Distribution curve of number of cement specimens and time limits within which they cracked due to shrinkage after hardening.



because of its restrained drying shrinkage. To eliminate the need for an operator on a 24-hr basis to read the length changes of the specimens, an automatic camera was set up to photograph the equipment with its dial gages and clocks once an hour. The pictorial records indicated the length attained by each prism when the corresponding annular specimen broke.

In general, the results of the investigation show that the cements with high shrinkage rates during the first hour after removal from the mold tended to crack sooner than the cements with lower shrinkage rates. The shortest time required for cracking of an annular specimen was 4 min, and the longest was over 45 hr. The shrinkages of the corresponding prisms were 0.005 and 0.126 percent, respectively. A considerable range in the shrinkage of the different cements over a 28-day test period was noted from 0.154 to 0.525 percent.

[1] *The use of annular specimens in the study of drying shrinkage appears to have been first reported by R. W. Carlson,* Cracking of concrete, *presented before the Boston Society of Civil Engineers, January 1942.*

Control of Cracks in Reinforced Concrete

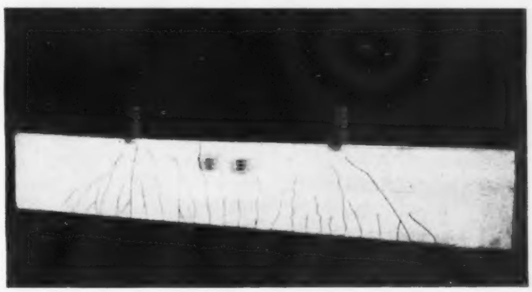
DETAILED INFORMATION on the cracking of loaded concrete beams and slabs is now available as a result of recent investigations.[1] The data promise to prove useful in controlling the spacing and width of cracks in the future design of reinforced concrete structures. In general the results show that width of cracks can best be controlled by using a large number of small reinforcing bars and by increasing the ratio of reinforcement. The investigation was carried out in the structural engineering laboratories by A. P. Clark of the American Iron and Steel Institute's Research Fellowship at the Bureau.

Formation of tensile cracks in reinforced concrete flexural members containing conventional, nonprestressed reinforcement is usually unavoidable since concrete has a low extensibility. While cracks barely wide enough to be visible may be objectionable only because of appearance, cracks of appreciable width can be a source of danger because of the possibility of corrosive agents attacking the steel reinforcing bars. Excessive width of cracks can also permit undesirable leakage in such hydraulic structures as dams, tanks, or pools. By increasing the bond strength between concrete and steel with improved reinforcing bars, widths of cracks may be reduced. During the past 10 years, the reinforcing bar industry has developed such improved deformed reinforcing bars. Results of a previous investigation [2] with axially-loaded cylindrical specimens show that the improved bars reduce crack width 20 to 40 percent compared to older bar designs. However, until the recent investigation there had been no systematic tests with beam and slab specimens with the new and improved bars. The investigation was undertaken to provide data on beam specimens containing the new type of reinforcing bars.

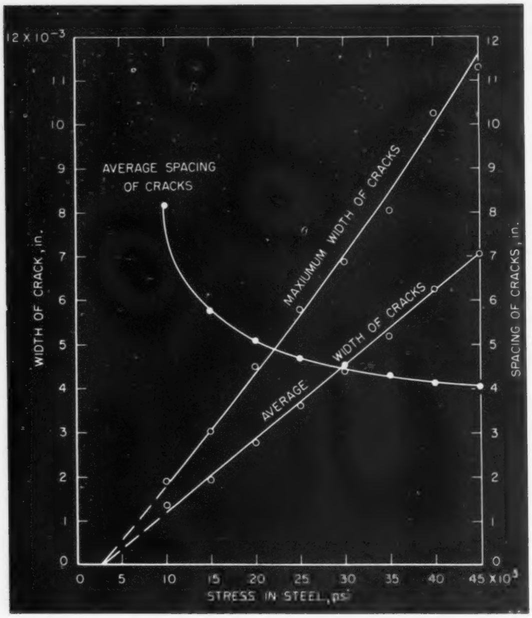
The study of crack formation included tests on 58 beam and slab specimens. The beams were of two sizes: 6 in. by 15 in. by 11 ft, tested on a 9-ft span; and 6 in. by 23 in. by 13 ft, tested on an 11-ft span. The slabs measured 6 in. deep, were from 6 in. to 15 in. wide and 8 ft long, and were tested on a 6-ft span. All specimens were tested as simply supported beams with loads applied at quarter points.

The specimens were cast in steel molds, and all were from the same type of concrete mixture. The tensile reinforcement—deformed bars of a commercially available design [3]—was placed near the bottom of the mold. Three standard 6- by 12-in. cylinders were cast with each specimen to determine the compressive strength of the concrete. These cylinders were cured and stored in the same manner as the specimens, and were tested at the same time.

The widths of the cracks were measured with 6-in. Tuckerman optical strain gages equipped with 0.5 in. lozenges. In order to include every crack that might form within the region of constant bending moment, two rows of these gages were located at equal distances from the longitudinal center line of the specimens. The gages in the two rows were staggered and overlapped 0.5 in. Strains in the tensile reinforcement



Investigations of cracking of loaded concrete beams promise to provide useful information in reducing the number and width of cracks in future design of reinforced concrete structures. Illustrated here is 1 of 58 specimens tested in this investigation. It shows the formation of cracks produced by loading the reinforced beam in a 600,000-lb. hydraulic testing machine.



Experimental results obtained in the testing of concrete beams and slabs reinforced with improved reinforcing bars. Graph shows range of spacing and widths of cracks for various steel stresses.

were determined with electric strain gages, and deflection at the center of the span was measured with taut-wire scale devices, with the wires stretched between two points directly over the supports.

The tests were performed in a 600,000-lb capacity hydraulic machine. To facilitate placing and reading the Tuckerman gages, the specimens were tested in an inverted position. The load was applied in increments which ranged from 500 to 5,000 lb, and the loading proceeded until the specimen failed by yielding of the reinforcement. Location and extent of cracks were recorded immediately following application of each increment of load.

For individual beam specimens, the ratio of maximum width of crack to the average width ranged from 1.18 to 2.77. However, the average maximum width of crack was about 1.64 times the average width for each value of stress considered, where the computed steel stresses ranged from 15,000 to 40,000 psi. Where the computed stress in the steel was 20,000 psi, crack width ranged from 0.001 to 0.005 in.; for 30,000 psi, the values ranged from 0.002 to 0.007 in.; at 40,000 psi, 0.004 to 0.010 in. The average spacing of cracks decreased rapidly with an increase in steel stress beyond that causing the first crack, and at a stress of 30,000 psi or more the average spacing appeared to approach a constant value. For individual specimens, the minimum average crack spacing varied from approximately 3 in. to nearly 7 in., with a 4-in.-average spacing for all of the specimens.

Since concrete is a heterogeneous material and cracks occur at random, the location and spacing of cracks are subject to considerable variation. While the results showed considerable scatter, it was found that an equation, which had been previously derived for symmetrically reinforced and axially loaded specimens,[4] could be adapted to flexural members. The average width of cracks was found to be proportional to the increase in steel stress beyond that causing initial cracking. The average width is also proportional to the product of two parameters D/p and $(h\text{-}d)/d$, where D is the diameter of the bar, p is the ratio of reinforcement, and h and d are respectively the over-all and effective depths of the beams. These observations are in qualitative agreement with the findings of other investigators who reported that the width of cracks can be reduced by using a large number of small bars and by increasing the ratio of reinforcement.

[1] *For further technical information, see* Investigation of cracking in reinforced concrete flexural members, *A. P. Clark, J. American Concrete Inst. (in press).*

[2] Effect of type of bar on width of cracks in reinforced concrete subjected to tension, *D. Watstein and N. A. Seese, Jr., J. Am. Concrete Inst.* **16**, *293 (Feb. 1945).*

[3] *The bar met the requirements of ASTM tentative specification for minimum requirements for the deformations of deformed steel bars for concrete reinforcement, A 305–50T.*

[4] Width and spacing of cracks in axially reinforced cylinders, *D. Watstein and D. E. Parsons, J. Research NBS* **31**, *1 (1943) RP1545.*

Postdoctoral Research Associateships Granted by NBS

SEVEN outstanding young scientists chosen from leading universities begin postdoctoral basic research this year at the National Bureau of Standards. The postdoctoral students will initiate a plan for advanced basic study whose cooperative sponsorship was announced last year by the National Academy of Sciences-National Research Council and NBS. The 7 fields chosen for study from among 13 areas are quantum chemistry, crystal structure, nuclear physics, physical chemistry, molecular structure and spectroscopy, mathematics, and statistical mechanics.

The Postdoctoral Research Associateships were first announced by the National Academy of Sciences and the Bureau in October of 1954. The program will provide advanced training, through Bureau sponsored research, to highly selected young scientists who have shown special promise of becoming creative leaders in basic research. This purpose will be accomplished in several ways. The Research Associates, while acquiring new basic knowledge, will have opportunities for developing new scientific approaches and laboratory skills, thus advancing scientific knowledge. They may

The microwave spectra of unstable molecules will be one of the problems studied under the Postdoctorial Research Associateship program initiated this fall. Part of this work will be performed in the molecular structure laboratory of the Thermodynamics Section.

also benefit from close contact with outstanding NBS scientists and the national and international scientific leaders with whom the Bureau is associated.

Postdoctoral study and research lasting for a year or more is a tradition among scientists. Many of the country's scientific leaders used such work to round out their education before settling on the field of research for which they are best known. In recent years the number of opportunities for such postdoctoral appointments has not kept up with the need; in fact, one of the most sought after fellowships in the physical sciences in existence since World War I has been discontinued.

The Bureau is vitally concerned with the expanding frontiers of science, particularly in basic research on physical standards and constants, the properties of matter, and measurements. Its program covers diverse areas of physics, mathematics, chemistry, and engineering, and therefore offers interesting opportunities for postdoctoral fellowship study. The research associateship program is directed by Dr. Wallace R. Brode, Mr. Joseph Hilsenrath, and Dr. David E. Mann of NBS. Supervising the program for the National Research Council are Dr. M. H. Trytten, Director of Scientific Personnel, and Dr. Claude Lapp, Director of the Fellowship Office. For the initial program, 13 areas were selected as offering possibilities for postdoctoral research. They were: Pure and applied mathematics; applied mathematical statistics; numerical analysis; experimental thermodynamics and calorimetry; statistical mechanics; molecular structure and spectroscopy; low temperature, solid state, theoretical, nuclear, and radiological physics; and analytical, inorganic, and physical chemistry. Other areas will be added to the program and made available to future candidates.

In applying for the postdoctoral positions, all applicants sought close association with particular NBS staff members. Also, several applicants expressed interest in using some of the Bureau's unusual equipment such as the special solenoid for the very precise measurement of electrical quantities and the versatile SEAC digital computer.

The seven scientists chosen for study during 1955–56 and their research fields are as follows:

Peter Leopold Bender, Rutgers University, Leiden University (Holland), Princeton (Ph. D.). Dr. Bender plans to redetermine, in absolute units, the gyromagnetic ratio of the proton by measuring the proton precession frequency in a 10 gauss magnetic field. The free precession technique will enable Dr. Bender to use the solenoid of the Bureau's extremely precise current balance. From the gyromagnetic ratio the magnetic moment of the proton can be obtained.

Richard James Prosen, University of Minnesota, University of California at Los Angeles (Ph. D.). Dr. Prosen plans to apply the computer SEAC to an investigation of crystal structure, with particular emphasis on problems of atomic arrangement. He hopes to answer the question, "How much and how well can an electronic computer be used in such problems?"

Alan Joseph Goldman, Brooklyn College, Princeton University (Ph. D., Jan. 1956). Mr. Goldman will conduct basic research in the theory of games. Using SEAC, he will try to replace the highly simplified models now used in the theory with more realistic models. This research has considerable interest to military and economic planners.

Morris Krauss, City College of New York, University of Utah (Ph. D.). Dr. Krauss plans a theoretical quantum mechanical study of the relationship between electron energy levels and molecular structure. Such calculations may help explain certain basic problems that are important in other fields such as mass spectrometry. SEAC will be the primary tool used in the study. Dr. Krauss will attempt to answer two questions: "How do you go about solving such a highly complex problem?" and "Of what value are known methods?"

Richard Ellsworth Nettleton, Amherst College, Brown University (Ph. D.). Dr. Nettleton will study the statistical mechanics of time dependent processes in large numerical systems of molecules. The problem will embrace the extension of the kinetic theory of gases to include triple-collision effects that are manifest in somewhat compressed gases. Dr. Nettleton will be attempting to advance the theory covering the more realistic dynamic situation found in the kinetic theory of gases.

Robert John Kurland, California Institute of Tech., Harvard University (Ph. D.). Dr. Kurland will conduct a study of free radicals and other unstable molecular species using microwave and other spectroscopic techniques. The purpose of this primarily experimental work is to obtain information on molecules that will allow prediction of their thermodynamic properties.

Bernard Jerome Ransil, Duquesne University, Catholic University (Ph. D.). Dr. Ransil is interested in the quantum statistical treatment of isotope effects. By deriving the higher order terms in the quantum mechanical partition function he hopes to predict the thermodynamic and transport properties of isotopically substituted compounds over wide temperature and density ranges. Dr. Ransil will also test the theoretical methods by making experimental vapor pressure studies of isotopic systems.

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TECHNICAL NEWS BULLETIN

U. S. DEPARTMENT OF COMMERCE
SINCLAIR WEEKS, *Secretary*
NATIONAL BUREAU OF STANDARDS
A. V. ASTIN, *Director*

September 1955 Issued Monthly Vol. 39, No. 9

For sale by the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C. Subscription price, domestic, $1.00 a year; 35 cents additional for foreign mailing; single copy, 10 cents. The printing of this publication has been approved by the Director of the Bureau of the Budget, March 6, 1953.

Contents

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Technical News Bulletin, volume **39**, No. 8, August 1955. 10 cents. Annual subscription $1.00; 35 cents additional for foreign mailing.

CRPL–132. Basic Radio Propagation Predictions for November 1955. Three months in advance. Issue August 1955. 10 cents. Annual subscription $1.00; 25 cents additional for foreign mailing.

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RP2605. Absolute calibration of the National Bureau of Standards photoneutron standard. J. A. De Juren, D. W. Padgett, and L. F. Curtiss.

RP2606. A fast responding electric hygrometer. Arnold Wexler, Samuel B. Garfinkel, Frank E. Jones, Saburo Hasegawa, and Albert Krinsky.

RP2607. A simplified method of measuring the marginal powers of spectacle lenses. Francis E. Washer.

RP2608. Thermodynamic properties of the alkali metals. William H. Evans, Rosemary Jacobson, Thomas R. Munson, and Donald D. Wagman.

RP2609. Arc and spark spectra of ruthenium. Karl G. Kessler and William F. Meggers.

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